Comparison of Remotely Sensed Images for Identification of Land Cover Types in Greater Vancouver Regional District

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Abstract
The need to identify and protect critical natural areas in the Greater Vancouver Regional District (GVRD) and other rapidly expanding urban areas is urgent. Land cover maps derived from ground-based land surveys and/or the interpretations of aerial photographs are time-consuming to produce and become quickly outdated as the landscape is altered. Instead, the automated classification of satellite images can efficiently generate up-to-date land cover maps. However, given the accuracy required for the land cover maps and the costs associated with obtaining the satellite images, it is first necessary to demonstrate the efficiency and efficacy of this technique. This study compared the accuracy, time, and costs associated with land cover map development for a 10km x 10km sub-urban test area in Langley, BC based on digital images from three satellite sensors: (1) the Landsat Enhanced Thematic Mapper Plus (ETM+) carried by the Landsat 7 satellite; (2) the Synthetic Aperture Radar (SAR) carried by RADARSAT1; and (3) the IKONOS carried by IKONOS 2. Objectives of the research are: (1) to determine the relative merits of each of the land classification technologies and their applicability to urban settings and (2) to supply local government agencies with data they need to support protection of natural areas in the GVRD.

Context and objectives
The expanding human population and concomitant demand for resources have resulted in an incontrovertible deterioration of the earth's ecosystems. This conflict between resource demands and nature is acutely apparent in urban settings, such as the Greater Vancouver Regional District (GVRD), a 3,292-km^2 area in southwestern British Columbia, Canada, where human density is high and where natural areas are quickly disappearing. Natural areas provide habitat for plants and animals, and conduits for their dispersal. Equally important, natural areas provide services such as storage and filtration of drinking water and opportunities for recreation. The need to identify and protect natural areas in the GVRD and other urban areas is urgent.

A critical component to satisfactory protection of natural areas in the GVRD is an up-to-date, high-resolution spatial dataset describing current land cover (vegetation, water bodies, impermeable surfaces, etc.). The goal for our project was to test the accuracy and efficiency of satellite images to provide this dataset for a 100-km^2 pilot area in the Township of Langley, British Columbia. This project was a coordinated effort between the Simon Fraser University School (SFU) of Resource and Environmental Management and the British Columbia Ministry of Water, Land, and Air Protection (MWLAP) Biodiversity Conservation Initiative.

The MWLAP Biodiversity Conservation Initiative is working to protect natural areas across the GVRD. The results of this project will be used to guide the development of a land cover map for the entire GVRD. In turn, this map will be used by MWLAP to produce maps describing currently undeveloped sites according to their value as habitat for plants and animals, as reservoirs for biodiversity, and to promote human services (recreation and water quality). Ultimately, these maps will serve as input to the planning process of the municipalities comprising the GVRD, as they offer a means to both ascertain the value of natural areas within the municipal bounds as well is in the context of the GVRD as a whole.

Background
A variety of commercial and non-commercial satellites provide imagery of the earth's surface is available for purchase. These satellites vary in the resolution at which images are captured, the wavelengths at which reflected electromagnetic radiation is recorded, and whether they are passive (record reflected radiation originally produced by the Sun) or active (generate and direct radiation toward the Earth and record its backscatter). For this project, images from three satellites, RADARSAT-1, Landsat ETM, and IKONOS, were purchased.

RADARSAT-1 images are recorded at a high spatial resolution, which is helpful for MWLAP's planning purposes. RADARSAT-1 is an active sensor, generating (and recording) radiation in a single band of the microwave range that produces images not compromised by cloud cover (a frequent occurrence in the GVRD). Both Landsat ETM and IKONOS are passive sensors that record reflected solar radiation in multiple spectral bands. IKONOS images have finer resolution than the Landsat images but record reflected reflection in fewer spectral bands.

Methodology

Sample Design

The Langley study site was chosen because the variety and relative abundance of land cover classes in its bounds are considered characteristic of many other locations across GVRD. In addition, the Langley Environmental Partners Society (LEPS) had recently completed an accurate land cover map (in the form of GIS-based polygons) for the pilot area (based on aerial photograph interpretation from 1995 orthophotos). Senior SFU Geography students also completed a second aerial photo-interpretation of 2002 colour orthophotos of the same pilot area. Langley (total area 303 km^2) is also one of the fastest growing municipalities in the GVRD and therefore a high priority for the MWLAP Biodiversity Conservation Initiative.

The classification scheme (Figure 1) used to describe land cover in our test site was based on that used during the previously conducted photo-interpretation, but modified to accommodate the intended use for the land cover map we would produce.

I. water
II. vegetation
    a. wetland
    b. shrubs
    c. forest
        1. deciduous
        2. coniferous
III. low disturbed (impervious surfaces/agricultural fields)

Figure 1. Land cover classification scheme

The required number of test points (sites at which actual land cover is indicated by the center of the photo-interpretation based polygons) was calculated based on the proportion of the test area covered by each land cover type according to the following formula (Congalton and Green 1999):

$$n_i = B\pi_i (1- \pi_I) / b_i^2$$

where:

i	=	land cover type (in our case there were 7)
B	=	a constant derived from the Chi-squared distribution
π_i	=	the proportion of land covered by i
b_i	=	the desired level of precision

Classification of Satellite Images

Two RADARSAT (summer and winter) images, one IKONOS image (summer), and two Landsat images (summer and winter) were analyzed using ERMapper 6.3 (Earth Resource Mapping, Ltd. 2002).

Dates	Sensor	Resolution	Number of bands
9/16/00, 11/27/00	RADARSAT-1	8m	1
6/28/00, 1/22/01	Landsat ETM	30m	7
6/25/00	IKONOS	4m	4

All images were first geo-referenced to the photo-interpretation-based polygons (RMS error was kept below 1 pixel). The images were then clipped to match the boundaries of the Langley test area. Speckle was removed from the RADARSAT images with a 5x5 average filter. Principle Components Analysis was used on the Landsat and IKONOS images to improve the explanatory power of the raw image data. An unsupervised classification (ISOCLASS unsupervised classification; maximum number of classes: 25) of each image was combined with information from the test site polygons to create training regions for each image. Using these training regions, a supervised classification (maximum

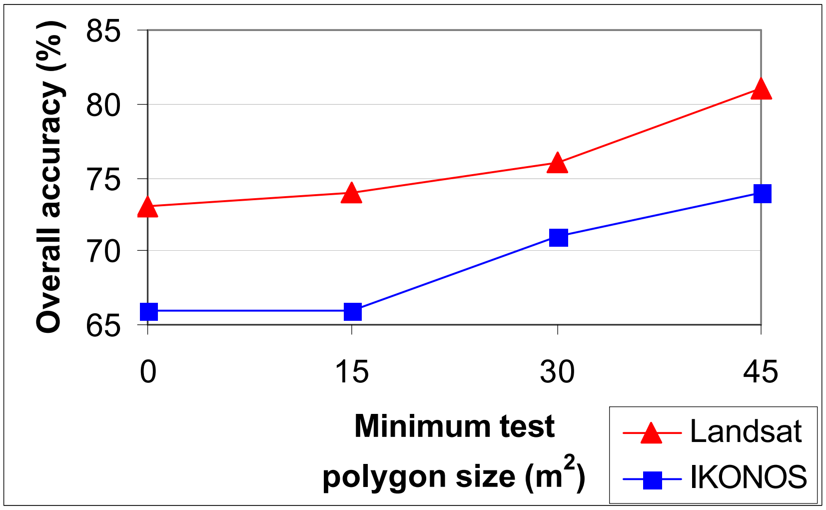

Figure 2. Classification accuracy for the five satellite images.

likelihood enhanced) was then performed on each image. The test points were used to generate an error matrix for each single image. The relationship between the minimum-size of the test polygons and the calculated accuracy of the classifications was also tested. The spectral signatures of the training regions from the clipped image with the highest classification accuracy (the Landsat summer image; see below) were used to classify the entire (unclipped) Landsat image.

Results/Conclusions

The Landsat summer image consistently yielded the highest overall classification accuracy (Figure 2). An accuracy level of 81% was achieved for this image for test data generated from test polygons greater than or equal to 45m^2. This accuracy came close to the 85% level that is a standard cutoff (Congalton and Green 1999) between "acceptable" and "unacceptable" results for our desired land cover classification scheme. The error matrix (and derived producer's and user's accuracy) from the summer Landsat image for test polygons larger than 45m^2 (Table 2) suggests that the classification was highly accurate for three of the six land cover types: coniferous trees, deciduous trees, and low-disturbed. The classification accuracy for shrubs, wetlands and water was low.

Table 2. Error matrix for the summer Landsat image (test polygons >45m^2).

Classified Image	Test Points						Grand Total	User's Accuracy
	coniferous	deciduous	shrubs	water	wetland	low-disturbed		
coniferous	11	1	0	4	0	1	17	65%
deciduous	0	22	0	0	3	4	29	76%
shrubs	0	0	0	0	2	0	2	0%
water	0	0	0	1	0	0	1	100%
wetland	0	0	1	0	19	7	27	70%
low-disturbed	2	1	0	2	16	137	158	87%
Grand Total:	13	24	1	7	40	149	234	
Producer's Accuracy	85%	92%	0%	14%	48%	92%	Overall Accuracy:	81%

The lower classification accuracy (74% overall accuracy) of the IKONOS image was a surprise given their fine resolution and multi-spectral quality (Table 3). However, it is precisely this feature that gives IKONOS lower overall accuracy results than Landsat. Figure 3 shows that the high-resolution (4m) pixels IKONOS sensors pick up more variation in land cover than do the interpreters creating the test polygons. The result is a classified IKONOS image that is highly 'speckled' compared to the original test polygons. Landsat on the other hand, because it is characterized by lower-resolution 30m pixels, produces a smoother image that is less ‘speckled’ and agrees more frequently with the test data. The error matrix (and derived producer’s and user’s accuracy) from the summer IKONOS image for test polygons larger than 45m^2 (Table 3) suggests that the classification was highly accurate for four of the six land cover types: coniferous trees, deciduous trees, low-disturbed, and water. The classification accuracy for wetlands was low, and there were no shrub test points in the IKONOS study site.

Table 3. Error matrix for the summer IKONOS image (test polygons >45m^2).

Classified Image	Test Points					Grand Total	User's Accuracy
	coniferous	deciduous	low-disturbed	water	wetland		
coniferous	**11**	2	5	0	7	25	44%
deciduous	2	**17**	1	0	11	31	55%
low-disturbed	0	0	**116**	0	12	128	91%
water	0	0	0	**6**	0	6	100%
wetland	0	0	15	0	**6**	21	29%
Grand Total:	13	19	137	6	36	211	
Producer's Accuracy	85%	89%	85%	100%	17%	**Overall Accuracy:**	**74%**

RADARSAT consistently performed poorly (accuracy <65%). A considerable level of corner reflection was observed throughout the RADARSAT images. Buildings, with distinctly vertical surfaces adjacent to distinctly horizontal surfaces, produced corner reflection as would be expected. But the bright corners were simply merged with the high intensity backscatter normally associated with impervious surfaces. Corner reflection also occurred, however, along the edges of forested patches that were adjacent to low-disturbed/shrub/wetland patches. Most of these edges are “artificial” in the sense that an unnatural discontinuity between the land cover types has been imposed and is being maintained by human intervention. The result is that there is no “smooth” (non-corner-reflecting) ecotone that might otherwise exist between these two land cover types in an undisturbed system. These bright corners were mistakenly classified as being impervious surfaces. In a less-disturbed landscape, these errors would be less likely to occur. The filtered summer and winter RADARSAT images offered revealing visual information on the study site. Building tops and water bodies were easily discernable, and vegetated vs. non-vegetated areas could readily be distinguished. The overall classification accuracy of the summer, winter, and summer/winter images did not meet the 85% level that is a standard cutoff (Congalton and Green 1999) between “acceptable” and “unacceptable” results for our desired land cover classification scheme. However, the RADARSAT images are still useful in two important ways: (1) as a “first pass” for land cover classification to refine the efficiency with which ground-based surveys or photo-interpretation exercises are performed; and (2) to track temporal patterns of the conversion of land between vegetated and non-vegetated states.

Qualitatively, the classification of the complete Landsat summer image appears reasonable. Disturbed surfaces in the intensely developed areas, such as downtown Vancouver, are easily discernable. Coniferous forests dominate the landscape north of the developed areas on the north shore. Predominantly low-disturbed cover, interspersed with deciduous forest fragments, spreads from east to west, south of the Fraser River. However, some instances of misclassification are also apparent. Snow at high altitudes is classified as exposed soil or NODATA (did not match the spectral signatures of any of the training regions). The mouth of the Burrard Inlet is classified as coniferous forest. The Fraser River is classified as NODATA. These mistakes could easily be corrected with supplemental digital spatial data mapping elevation and hydrology.

Overall accuracy is affected by minimum test polygon size. The larger the homogeneous area around a test point, the greater the probability it will be correctly classified. The increasing classification accuracy with increasing minimum test polygon size for all images suggests that it may be possible to obtain an acceptable accuracy rating if larger minimum test polygon sizes were acceptable or if the landscape is less where patch size for the various land cover types is larger. As long as the scale of resolution at which the classified image meets accuracy requirements is consistent with planning needs, the classified satellite image will be a useful tool for planning.

Further analysis of other unique landscapes in the GVRD (the North Shore for example) and of how changes in the test data set affect the ranking of the satellite alternatives is ongoing.

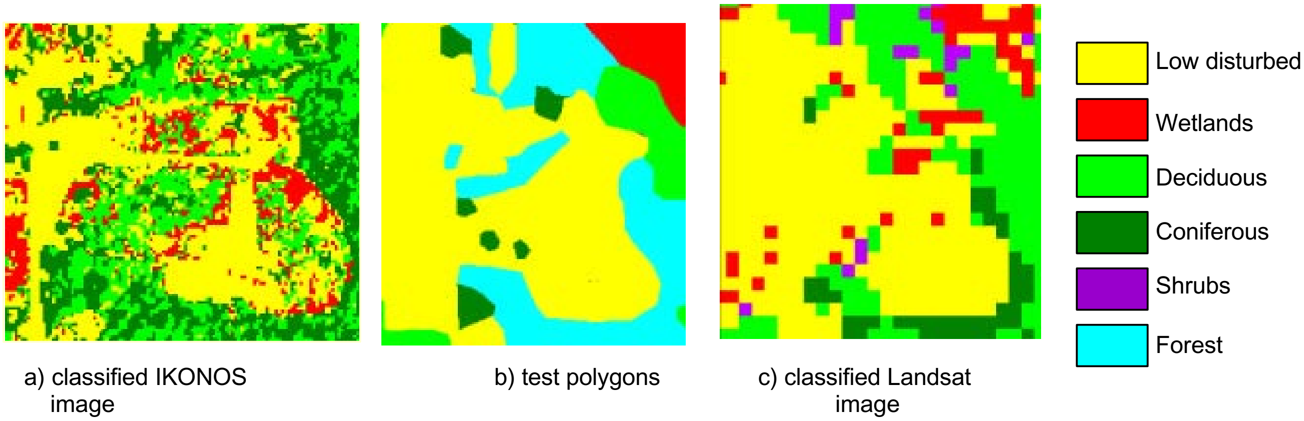

Figure 3. The classified IKONOS image captures greater detail than both the classified Landsat image and the test polygons.

Acknowledgments
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References
Congalton, R. G. and K. Green, 1999, *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, Lewis Publications, Boca Raton, FL.

Earth Resource Mapping, Ltd., 2002, ER Mapper.

Appendix A: Change in Landsat accuracy with increasing test polygon size.

a) All test polygons

Classified Image	Test Points coniferous	deciduous	shrubs	water	wetland	low-disturbed	Grand Total	User's Accuracy
coniferous	**24**	2	1	20	1	10	58	41%
deciduous	7	**46**	1	1	3	20	78	59%
shrubs	0	1	**0**	0	2	3	6	0%
water	0	0	0	**2**	0	0	2	100%
wetland	1	2	2	0	**20**	22	47	43%
low-disturbed	19	10	10	27	24	**418**	508	82%
Grand Total:	51	61	14	50	50	473	699	
Producer's Accuracy	47%	75%	0%	4%	40%	88%	Overall Accuracy:	**73%**

b) Test polygons > 15m^2

Classified Image	Test Points coniferous	deciduous	shrubs	water	wetland	low-disturbed	Grand Total	User's Accuracy
coniferous	**21**	2	1	20	0	8	52	40%
deciduous	7	**39**	0	0	3	10	59	66%
shrubs	0	1	**0**	0	2	3	6	0%
water	0	0	0	**2**	0	0	2	100%
wetland	1	0	1	0	**20**	14	36	56%
low-disturbed	10	6	7	25	22	**315**	385	82%
Grand Total:	39	48	9	47	47	350	540	
Producer's Accuracy	54%	81%	0%	4%	43%	90%	Overall Accuracy:	**74%**

c) Test polygons > 30m^2

Classified Image	Test Points coniferous	deciduous	shrubs	water	wetland	low-disturbed	Grand Total	User's Accuracy
coniferous	**16**	1	1	15	0	3	36	44%
deciduous	2	**30**	0	0	3	5	40	75%
shrubs	0	1	**0**	0	2	1	4	0%
water	0	0	0	**1**	0	0	1	100%
wetland	0	0	1	0	**19**	9	29	66%
low-disturbed	4	4	4	9	20	**205**	246	83%
Grand Total:	22	36	6	25	44	223	356	
Producer's Accuracy	73%	83%	0%	4%	43%	92%	Overall Accuracy:	**76%**

d) Test polygons > 45m^2

Classified Image	Test Points coniferous	deciduous	shrubs	water	wetland	low-disturbed	Grand Total	User's Accuracy
coniferous	**11**	1	0	4	0	1	17	65%
deciduous	0	**22**	0	0	3	4	29	76%
shrubs	0	0	**0**	0	2	0	2	0%
water	0	0	0	**1**	0	0	1	100%
wetland	0	0	1	0	**19**	7	27	70%
low-disturbed	2	1	0	2	16	**137**	158	87%
Grand Total:	13	24	1	7	40	149	234	
Producer's Accuracy	85%	92%	0%	14%	48%	92%	Overall Accuracy:	**81%**

Appendix B. Change in IKONOS accuracy with increasing test polygon size

a) All test polygons

Classified Image	Test Points					Grand Total	User's Accuracy
	coniferous	deciduous	low-disturbed	water	wetland		
coniferous	**29**	12	41	13	9	104	28%
deciduous	7	**34**	8	1	12	62	55%
low-disturbed	12	5	**308**	14	15	354	
water	0	0	1	**12**	0	13	92%
wetland	1	1	50	0	**7**	59	12%
Grand Total:	49	52	408	40	43	592	
Producer's Accuracy	59%	65%	75%	30%	16%	Overall Accuracy:	**66%**

b) Test polygons > 15m^2

Classified Image	Test Points					Grand Total	User's Accuracy
	coniferous	deciduous	low-disturbed	water	wetland		
coniferous	**25**	10	24	11	8	78	32%
deciduous	6	**29**	6	1	11	53	55%
low-disturbed	5	3	**235**	13	15	271	
water	0	0	1	**12**	0	13	92%
wetland	1	0	41	0	**7**	49	14%
Grand Total:	37	42	307	37	41	464	
Producer's Accuracy	68%	69%	77%	32%	17%	Overall Accuracy:	**66%**

c) Test polygons > 30m^2

Classified Image	Test Points					Grand Total	User's Accuracy
	coniferous	deciduous	low-disturbed	water	wetland		
coniferous	**16**	4	9	7	8	44	36%
deciduous	4	**25**	2	1	11	43	58%
low-disturbed	1	2	**164**	2	13	182	
water	0	0	0	**11**	0	11	100%
wetland	0	0	27	0	**6**	33	18%
Grand Total:	21	31	202	21	38	313	
Producer's Accuracy	76%	81%	81%	52%	16%	Overall Accuracy:	**71%**

d) Test polygons > 45m^2

Classified Image	Test Points					Grand Total	User's Accuracy
	coniferous	deciduous	low-disturbed	water	wetland		
coniferous	**11**	2	5	0	7	25	44%
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